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Upper Body Fatiguing Exercise and Shooting Performance

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This study assessed the effect of upper extremity muscle fatigue on shooting performance while in a standing, unsupported firing position. Nine male and three female soldiers fired at targets before and after performing upper extremity exercise to fatigue using both (1) an upper body ergometer and (2) a Military Operations in Urban Terrain obstacle course. Shooting accuracy, assessed by the number of hits, misses, and shot group size, was significantly decreased ($p < 0.05$) immediately following both types of exercise and recovered to pre-exercise values within 5 minutes for all measures except the number of misses, which returned to pre-exercise values by 10 minutes. There was no relationship between fitness measures and shooting performance, although muscle endurance was a factor in the duration of exercise prior to fatigue. We conclude that shooting accuracy recovers rapidly in fit soldiers following fatiguing lifting, climbing, and pulling activity.

Introduction

Military training is increasingly focused on the ability to negotiate military operations in urban terrain (MOUT).[1] To successfully maneuver personnel and equipment through a MOUT environment, soldiers must perform climbing, carrying, lifting, and pulling tasks that require significant upper body strength and endurance. Additionally, soldiers operating in a tactical environment must be prepared to immediately and effectively engage the enemy by fire.[2] Therefore, optimal performance of a combination of gross motor, fine motor, and visual-motor skills is required to ensure mission success.

Bodily fatigue following performance of physically demanding tasks may adversely affect marksmanship. Decrements in shooting accuracy have been observed following whole body endurance activities such as load carriage while marching,[3] litter carry maneuvers,[4,5] combined exposure to altitude and exercise,[6] and bicycle ergometry.[7] In biathletes, it has been further demonstrated that, although exercise intensity had minimal effect on accuracy for prone shooting, it did have a significant effect on shooting accuracy and stability of hold in the standing position.[7]

In a MOUT environment, firing a weapon in the standing, unsupported position is common.[1,2] Furthermore, shooting while standing is often the primary position of Special Operations Command warfighters, such as U.S. Army Rangers, Special Forces, and U.S. Navy Seals, who often find themselves in relatively close quarters while standing.[8] Whereas the record-fire test for the basic weapons (the M16A1 and M16A2) uses the supported firing position (foxhole) and prone unsupported positions,[9] analysis of combat data shows these two positions are used less than 20% of the time. Shooting while standing and kneeling are the more frequently used positions.[10]

Upper body strength and endurance are critical to maintaining a stable firing position in the standing, unsupported mode. To achieve a steady firing position, the butt of a shoulder-fired weapon must be secured in the pocket of the shoulder. To achieve this, the elbow flexor muscles contract concentrically to decrease the elbow angle, pulling the weapon against the shoulder. To maintain this stable firing position, the elbow flexors must continue to contract isometrically. If the upper extremity muscles involved in this action become fatigued following performance of other tasks, stability of hold may be affected, decreasing shooting accuracy.

The effect of localized upper extremity muscle fatigue on marksmanship has not been examined. This study examined the effects of upper body exercise performed to fatigue on marksmanship performance with the subject in a standing, unsupported firing position. We also assessed the time course for recovery to baseline shooting performance, and the effect of the soldier's level of physical fitness on shooting accuracy during recovery.

Methods

Experimental Design

This study compared shooting accuracy of 12 volunteers following two exercise bouts designed to fatigue the upper extremities. Two upper extremity exercise bouts performed to volitional fatigue were used as our exercise conditions: (1) hand-crank upper body ergometer (UBE) and (2) obstacle course (OC). Four measures of marksmanship (target hits, target misses, late fires, and shot group size) were used as our dependent variables and were measured at baseline, immediately after exercise, and 5, 10, and 15 minutes after exercise.

Subjects

Twelve active duty Army soldiers (nine males and three females) volunteered to participate in this study and completed all aspects of training and testing. All volunteers underwent a pre-study physical examination and gave their written informed consent. Volunteer characteristics are summarized in Table I. A self-rated rifle shooting accuracy profile, used to classify volunteers as a "beginner," "fair shooter," "good shooter," or "expert" determined that one subject was a beginner, seven were fair shooters, and four were good shooters. One individual was left-handed, three were ambidextrous and fired right-handed, and the remaining eight were right-handed.

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TABLE I

SUBJECT DESCRIPTORS BY GENDER (MEAN ± SD)

	Male (n = 9)	Female (n = 3)
Age (years)	24.6 ± 6.2	18.3 ± 0.6
Height (cm)	181.9 ± 6.6	151.6 ± 5.3
Weight (kg)	87.2 ± 12.0	53.6 ± 4.8
Time in service (years)	3.9 ± 3.1	0.78 ± 0.05

Procedure

Training and testing took place over a 2- to 3-week period, and were conducted at approximately the same time each day to limit the effect of circadian rhythm on shooting performance.[11] During the first week, volunteers performed marksmanship training until a plateau in shooting accuracy was achieved and were familiarized with all test procedures. Within 2 weeks of training, and on two separate test days, volunteers performed the baseline rapid firing test (RFT) followed by one of the two randomly selected upper body exercise conditions (UBE and OC). The RFT was administered again immediately and at 5, 10, and 15 minutes after exercise to assess recovery of shooting performance.

Questionnaires

Prior to testing, volunteers completed a demographic questionnaire that included general descriptors (age, height, weight, etc.) and self-assessed ratings of health and fitness to include the volunteer's most recent Army physical fitness test score, and shooting accuracy. The physical discomfort questionnaire,[12] which rates soreness, pain, or discomfort by body location, was completed before and after performing each test event to assure that any musculoskeletal complaints resulting from the exercise were able to be promptly evaluated by the medical monitor.

Marksmanship Training

Marksmanship performance was assessed using the model 7–57A Weaponeer rifle marksmanship trainer (Spartanics, Inc., Rolling Meadows, IL), which has been used extensively at the U.S. Army Research Institute of Environmental Medicine to evaluate rifle marksmanship performance in a laboratory setting. This device uses a modified M16A2 rifle, simulates realistic recoil, and has been shown to be predictive of live fire performance on the rifle range.[10] The Weaponeer has been used to quantify both speed (accuracy in hitting rapidly appearing pop-up targets) and variability (accuracy in terms of tightness of the shot group) components of rifle marksmanship[13–17] and is a reliable and valid method of assessing marksmanship when live fire is not an option.

Volunteers trained and tested on the Weaponeer while wearing the standard U.S. Army battle dress uniform with kevlar helmet. Each standardized training session consisted of (a) zeroing (firing a nonpaced series of nine shots at a scaled 25-m zeroing target while in a standing sandbag supported position until eight of nine shots fell within a 4-cm diameter circle) and (b) shooting at 32 randomly presented pop-up targets at simulated distances of 75, 175, and 300 m with and without sandbag support. The volunteers also practiced the RFT, which consisted of 1-minute cycles in which 12 targets were randomly presented for 2 seconds each at a simulated 75 m with the volunteer in a standing, completely unsupported firing position (Fig. 1). A Weaponeer trainer closely observed each volunteer's firing technique and gave appropriate feedback and instructions to improve and optimize the volunteer's shooting proficiency.

Fig. 1. The standing, unsupported firing position.

Rapid Fire Test

Rapid fire tests were administered before exercise, immediately after exercise, and at 5, 10, and 15 minutes after exercise. Immediately following exercise termination, the volunteer walked 3 to 4 m to the Weaponeer, donned a kevlar helmet, positioned the weapon in the standing, unsupported firing position, and commenced firing when the first target was presented. The first shot was fired approximately 15 seconds following completion of the exercise event. Twelve targets randomly popped up at a simulated 75 m for 2-second presentations. Firing time for completion of the RFT was less than 1 minute, allowing approximately 4 minutes of recovery prior to the next RFT. To assess marksmanship accuracy, each shot was recorded as a hit, a miss, or a late shot. Marksmanship precision was assessed by observing shot group tightness and was determined by counting the number of hits within a grid 2.33 × 2.33 cm using a previously described technique;[17,18] the higher score means a better shot group tightness.

Upper Body Fatiguing Exercise Conditions

The upper body exercise conditions use concentric, or shortening, contractions to fatigue the elbow flexor muscle group of both arms. Eccentric contraction, which occurs when muscle lengthens as it contracts, was avoided to prevent muscle damage that occurs with eccentric but not concentric or isometric muscle action.[19]

Arm-Crank Ergometry

An UBE (Cybex Metabolic Systems, Seattle, Washington) was used to perform concentric upper extremity exercise to exhaustion. Peak oxygen consumption (VO_{2peak}) was determined by oxygen-uptake analysis using a computerized expired gas analysis system developed at U.S. Army Research Institute of Environmental Medicine[20] during performance of a continuous arm-crank protocol at 60 rpm.[21] During the test procedure, subjects wore a mouthpiece through which their expired air was measured and analyzed. Heart rate was continuously monitored throughout the test using a single-channel three-lead electrocardiograph telemetry unit (model 1511B, Hewlett-Packard, Lexington, Massachusetts) and a heart rate monitor (model 145930, Polar Pacer, Port Washington, New York). With the crank axis height of the ergometer adjusted to shoulder level, the subject repetitively pulled the handles toward their body, using concentric contraction of the elbow flexor muscles to decrease the elbow angle. Subjects began continuously cranking the UBE at a workload of 400 kg/min (approximately 80 W) at a pace of 60 rpm for a 1-minute warm-up period, after which the workload was incrementally increased by 100 kg/min every 3 minutes. The investigator visually monitored the dial on the UBE to assure workload was maintained at a frequency of 60 rpm. Once VO_{2peak} was reached, the subject rested for 3 minutes, during which time the mouthpiece and electrocardiograph equipment were removed, and then cranked the UBE at 70% of VO_{2peak} until unable to maintain the workload at 60 rpm for 15 seconds.

Upper Body OC

An OC (Fig. 2) was designed and constructed to simulate four tasks conducted in a MOUT scenario that require significant upper body strength: (1) heel lift (assisting a soldier in entry through a window; Fig. 2a); 2) window entry (entry through a window; Fig. 2b); (3) rope pull (pulling equipment up to the third story of a building using a rope; Fig. 2c); and (4) sandbag stack (moving equipment in a "bucket brigade" action; Fig. 2d).

To simulate the heel lift, a pulley system was devised whereby a rope was threaded through a friction-based resistive training device (The Trainer, Thousand Oaks, California). We used an electronic force transducer (model CM-2, BLH Industries, Canton, Massachusetts) to assure the friction device was adjusted to where the volunteer lifted a simulated weight equal to 45.5 kg. As illustrated in Figure 2a, volunteers were asked to place their hands at belt buckle level and, with palms facing upward and fingers interlocked around the rope directly under the rubber

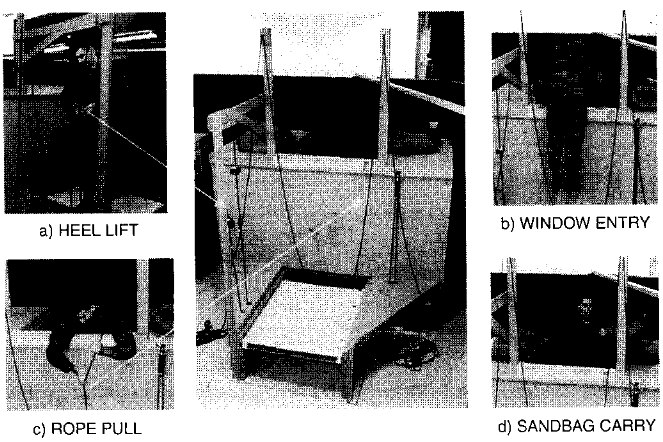

Fig. 2. Upper extremity OC events presented in order of performance.

heel, lift the heel from the level of the belt buckle to midchest using an elbow flexion action. Volunteers performed this single lift action six times, at a pace of one lift every 1.5 seconds (timed using an audible metronome set at 90 bpm).

Immediately following completion of the heel lift, subjects jumped through an open window (Fig. 2b) and stood on an adjustable platform that was positioned (on both sides) so that the sill of the window was at axillary height. The volunteer then faced the window with the midchest touching the sill, reached through the window with both arms and, using a concentric elbow flexion action alternating left to right, grasped and pulled 6.1 m of rope (equivalent to two stories) through a friction-based resistive training device identical to that used in the heel lift task (Fig. 2c). Using the electronic force transducer, we adjusted the friction device to simulate a 23-kg load. Pilot work determined that the frictional properties of the resistive device changed when the device heated up after pulling the rope through several times. To assure a consistent load, the temperature of the device was monitored by an electronic thermistor (Yellow Springs Instrument Co., Yellow Springs, Ohio), and the device was preheated to 98°F prior to beginning the OC. This was determined to be the temperature that resulted consistently in an equivalent 23-kg load of resistance. A metronome, set at 90 bpm, was used to pace the task (one pull per beat of the metronome).

Once the rope pull was completed, volunteers immediately began to move a total of fifteen 14.5-kg sandbags, one at a time, from a shoulder high pick-up point on a platform immediately to their right or left, to an opposite position approximately 1 m to the right or left of the pick-up point, depending on the start position (Fig. 2d). This task was paced at a rate of one sandbag for each four beats of the metronome.

Volunteers moved repetitively through the four-task circuit until upper body fatigue prevented them from continuing the tasks at the required pace, at which point the activity was terminated. Heart rate was monitored continually by a Polar heart watch (Polar Inc., Stanford, CT) as the volunteer moved through the course.

Data Analysis

A repeated measures analysis of variance was conducted on shooting performance measures following upper body fatiguing exercise using Statistical Package for the Social Sciences (SPSS Inc., Chicago, Illinois). Tukey post hoc comparisons were performed on measures with significant effects. Statistical significance was set at $p \leq 0.05$. Pearson correlation coefficients were used to assess the relationship between shooting accuracy and heart rate and fitness measures.

Results

Shooting Accuracy

Shooting performance measures are summarized in Table II. Fatiguing upper body exercise significantly decreased both shooting accuracy and shooting precision over time, assessed by hits ($p < 0.001$), misses ($p < 0.001$), and shot group size ($p < 0.001$); however, the number of shots fired late did not change at any point in time. There was no difference between exercise groups for any performance measure nor was there significant interaction between treatment and time.

TABLE II

SHOOTING PERFORMANCE FOLLOWING UPPER BODY EXERCISE EVENTS PERFORMED TO FATIGUE (MEAN ± SD)

AQ: tA

	Hits	Misses	Late	Shot Group
UBE				
Pre-exercise	5.83 ± 1.11	5.67 ± 0.98	0.50 ± 0.67	5.17 ± 1.03
Immediately after exercise	3.08 ± 2.15	8.92 ± 2.15	0.00 ± 0.00	3.92 ± 1.31
5 minutes after exercise	4.25 ± 2.49	7.58 ± 2.43	0.17 ± 0.39	4.75 ± 1.22
10 minutes after exercise	5.25 ± 1.86	6.50 ± 1.83	0.25 ± 0.45	5.58 ± 1.78
15 minutes after exercise	5.75 ± 2.09	5.58 ± 2.23	0.67 ± 1.07	5.33 ± 0.98
OC				
Pre-exercise	6.33 ± 1.97	5.17 ± 1.95	0.50 ± 0.67	5.33 ± 1.56
Immediately after exercise	3.42 ± 1.24	7.92 ± 1.31	0.67 ± 0.98	3.58 ± 1.31
5 minutes after exercise	5.00 ± 2.52	6.83 ± 2.55	0.17 ± 0.39	5.08 ± 1.73
10 minutes after exercise	5.83 ± 2.17	5.92 ± 2.15	0.25 ± 0.45	5.33 ± 1.44
15 minutes after exercise	5.92 ± 2.87	5.58 ± 2.39	0.50 ± 0.80	4.91 ± 1.00

Post hoc analysis of the effect of time following upper extremity exercise revealed that the mean number of hits was 46% lower than pre-exercise values immediately post-exercise ($p < 0.001$) but did not differ significantly from baseline at 5, 10, or 15 minutes after exercise (Fig. 3). Misses increased significantly immediately (by 55%) and at 5 minutes (by 33%) after exercise ($p < 0.001$ and $p = 0.02$, respectively) when compared to before exercise scores, but by the 10- and 15-minute mark, the number of misses had reached pre-exercise values (Fig. 4). Shot group tightness was 71% of pre-exercise values immediately following upper body exercise ($p = 0.006$), returned to pre-exercise level at 5 minutes, and stayed at baseline for the remaining 10-minute period (Fig. 5).

Heart Rate

Heart rate changed significantly over time ($p < 0.0001$) and was elevated from baseline for the entire 15 minutes after exercise period. The UBE condition resulted in greater overall heart rate elevation than the OC condition ($p = 0.001$). Further analysis of a significant time-by-treatment interaction ($p < 0.0001$) revealed that although heart rate at baseline and immediately after exercise did not differ between conditions, the heart rate at 5, 10, and 15 minutes was significantly higher following the UBE event than the OC event ($p < 0.001$; Fig. 6). A significant correlation was observed between heart rate and shot group size for the OC condition only at 10 and 15 minutes.

Fitness

Fitness measures of VO_{2peak} (mL/kg/min), self-reported Army physical fitness test score, and duration of exercise prior to fatigue (Table III) were not correlated with any marksmanship parameter.

Discussion

This investigation demonstrated that marksmanship performance in the standing, unsupported firing position was significantly decreased immediately following elbow flexion exercise performed to fatigue and did not differ between exercise conditions. Shooting accuracy and precision returned to pre-exercise values by 5 minutes after exercise for all marksmanship measures except the number of misses, which returned to pre-exercise values at 10 minutes after exercise. Our results are similar to other studies that have documented deficits in shooting accuracy following running, marching, and bicycling activ-

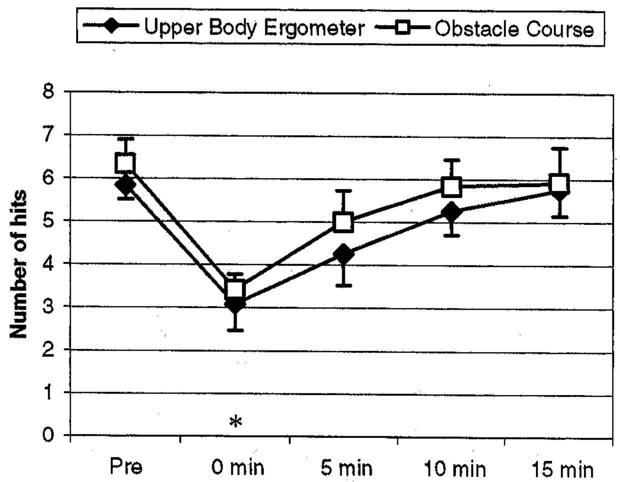

Fig. 3. Number of hits while shooting in the standing, unsupported position before (pre), immediately after (0 minute), and 5, 10, and 15 minutes following fatiguing upper extremity exercise (mean ± SEM). An asterisk denotes significance from baseline for both groups combined ($p < 0.05$).

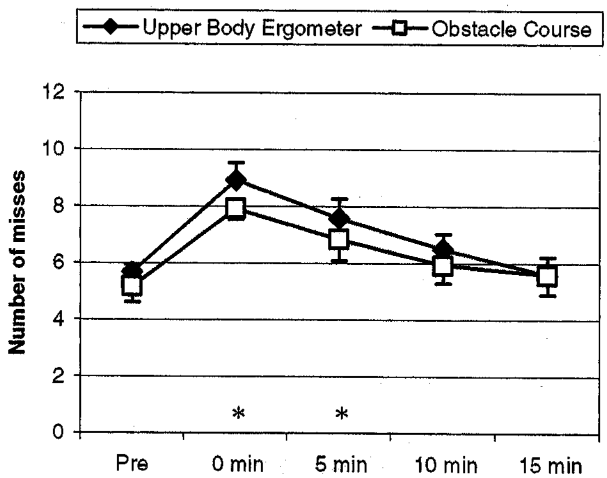

Fig. 4. Number of misses while shooting in the standing, unsupported position before (pre), immediately after (post), and 5, 10 and 15 minutes following fatiguing upper extremity exercise (mean ± SE). *, Significance from baseline for both groups combined ($p < 0.05$)

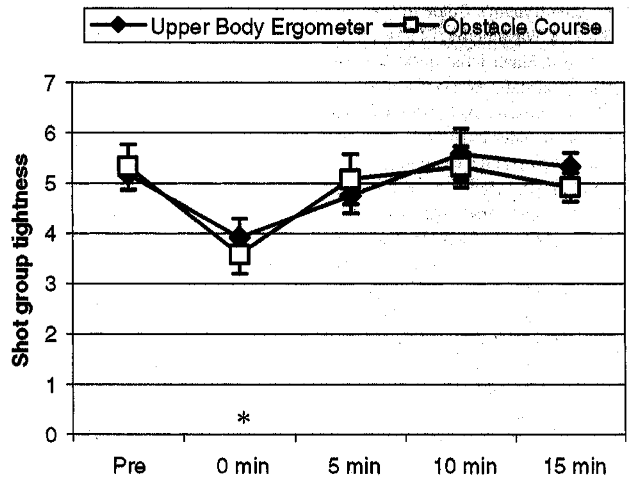

Fig. 5. Shot group tightness (precision) while shooting in the standing, unsupported position before (pre), imediately after (0 minute), and 5, 10, and 15 minutes following fatiguing upper extremity exercise (mean ± SEM). *, Significance from baseline for both groups combined ($p < 0.05$).

ities performed to fatigue.[3-7,17,22,23] However, shooting accuracy may have been affected by factors other than localized muscle fatigue as the muscles used to lift and stabilize a shoulder-fired weapon are minimally fatigued during these running, marching, and cycling activities.

Postural sway, resulting from variations in visual, proprioceptive, and equilibrium responses, may contribute to diminished marksmanship performance, particularly during firing in the standing, unsupported position.[24] Indeed, deficits in shooting performance of elite athletes have been observed following aerobic exercise of varying intensities in the standing position but were not observed when shooting from a prone position,[7] which were when the effects of postural sway would have been irrelevant. Although our exercise conditions involved little to no exercise of the lower extremities, fatigue of the trunk muscles used to stabilize the upper body may have contributed to increased postural sway, affecting marksmanship performance.

Changes in heart rate may also be associated with firing accuracy. In our study, shooting accuracy was most diminished immediately after exercise when the heart rate was highest. Using a laser mounted on a rifle barrel, researchers observed increased wobble diameter as heart rate increased following exercise of rising intensity,[7] which may affect shot group size. Whereas this was present in both prone and standing positions, the effects of increased heart rate had the most effect during firing in the standing, unsupported position. Indeed, deficits in prone shooting performance were observed in soldiers 12 minutes following an exhausting 3-hour road march, but after remaining prone for a 2-minute rest interval, marksmanship had returned to baseline values.[22] This rapid increase in accuracy may have been related to heart rate, which is approximately 20 bpm less in the prone position.[25]

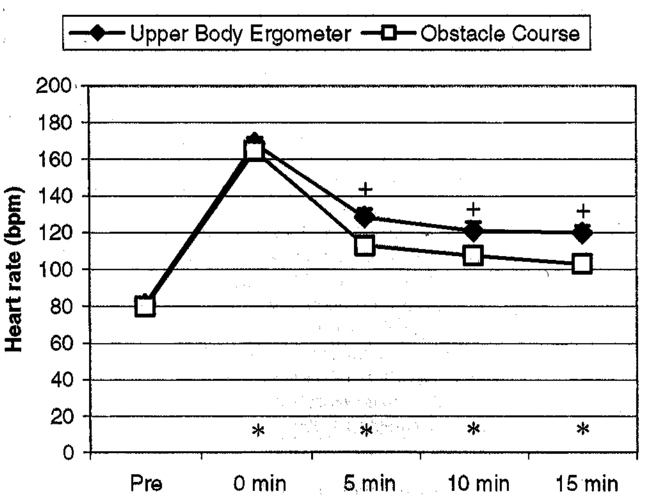

Fig. 6. Heart rate at baseline (pre) and immediately prior to rapid fire marksmanship tests conducted immediately after (0 minute), and at 5, 10, and 15 minutes following fatiguing upper extremity exercise (mean ± SEM). *, Significance from baseline for both groups combined; +, significant difference between groups ($p < 0.05$).

TABLE III

FITNESS MEASURES FOR MALES AND FEMALES COMBINED

	Mean ± SD
APFT score	242.5 ± 30.5
VO_{2peak} (mL/kg/min)	32.0 ± 3.9
Time to fatigue (minutes):	
UBE	26.5 ± 10.3
OC (5.2 ± 1.6 cycles)	7.2 ± 2.4

We observed no difference between exercise conditions in peak heart rate and heart rate immediately preceding firing. However, heart rate was greater for the UBE condition than the OC condition at 5, 10, and 15 minutes after exercise and was elevated from baseline for both conditions at all time points following exercise. Although both conditions achieved maximal heart rates at the point of fatigue, the UBE condition required a longer exercise period to achieve this than the OC condition (26.5 ± 10.3 minutes vs. 7.2 ± 2.4 minutes, respectively), which may explain the difference in recovery heart rate. While this did not affect recovery of baseline shooting performance, which did not differ between groups, heart rate was significantly and negatively correlated with the shot group tightness for the OC condition at 10 minutes ($r = -0.740$; $p = 0.006$) and 15 minutes ($r = -0.60$; $p = 0.04$). This was not seen following the UBE condition, but as heart rate was lower in the OC condition at these time points, this may indicate that heart rate reaches a point during recovery where wobble is significantly decreased, allowing for a tighter shot group.

The time required to reach muscle fatigue was not a factor in shooting accuracy following our exercise conditions with no difference in marksmanship performance between exercise performed for 26.5 ± 10.3 minutes (UBE) and 7.2 ± 2.4 minutes (OC). Previous studies have observed deficits in shooting performance after exercise lasting from between 2 and 15 minutes.[4,5] These studies used a litter carry exercise condition, which combined whole body exercise with lifting tasks using the elbow flexor muscles. Our hypothesis that firing accuracy might be affected by muscle fatigue of the elbow flexor muscles is supported by these studies. Rice et al.[4] observed decreased marksmanship performance immediately following litter carry exercise, irrespective of the time to fatigue, which ranged from 2.1 to 30.0 minutes in men and 1.1 to 30.0 minutes in women. Additionally, Tharion et al.[5] observed greater deficits in shooting accuracy following a 15-minute litter carry, which involved repetitive lifting of a 45-kg load to chest height, than 30-minutes of litter carry exercise that involved only prolonged carry. These results indicate that localized muscle fatigue of the elbow flexor muscles may decrease marksmanship performance regardless of the time required to reach fatigue.

We observed that both accuracy (the number of hits) and precision (shot group tightness) had recovered to baseline levels by 5 minutes after exercise and the number of misses by 10 minutes with similar recovery for both exercise conditions. As shots that were not classified as a hit were classified as either a late shot or a miss, a slight but nonsignificant decrease in shots fired late at the 10-minute mark may have resulted in the significant number of misses observed, even though the number of hits had returned to pre-exercise values. In the only other study to assess the time required to recover to baseline shooting levels following intense exercise, shooting performance recovered to baseline levels after 1.5 minutes and was maintained for the 12-minute period after exercise.[17] Whereas our study did not assess marksmanship recovery until 5 minutes after exercise, we confirmed that shooting accuracy decreased only temporarily following fatiguing exercise, as shown by the immediate RFT, and recovered within 5 minutes.

Fitness parameters of VO_{2peak}, Army physical fitness test score, and duration of exercise prior to fatigue were not correlated with shooting performance. Upper body anaerobic capacity and strength, however, has been significantly correlated with military performance in a field environment.[22] Although this study indicates that increased muscle fitness may not improve firing accuracy, it does increase the soldiers' ability to perform essential military tasks for a longer period of time prior to fatigue. Further study into how resistance training might improve performance of combat-related tasks, such as maneuver and fire through a MOUT environment, are recommended.

Conclusions

Our study provides evidence that fit soldiers can recover shooting accuracy following exhausting lifting, climbing, and pulling activities and can accurately and effectively engage the enemy by small arms fire after a very brief rest period. We believe that task-specific physical training programs are essential to sustaining military task performance in a tactical environment, where soldiers must often work to the point of fatigue. We recommend strength and endurance training of the upper body flexor muscle groups be incorporated into any resistance exercise program. As fatigue of these muscle groups temporarily affects shooting accuracy, it is essential to optimize the length of time soldiers can perform upper extremity tasks prior to muscle fatigue.

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References

1. Military Operations on Urbanized Terrain (MOUT). Army Field Manual (FM) 90-10. Washington, DC, Headquarters, Department of the Army, 1979.
2. An Infantryman's Guide to Combat in Built Up Areas. Army Field Manual (FM) 90-10-1. Washington, DC, Headquarters, Department of the Army, 1993.
3. Knapik J, Staab J, Bahrke M, Reynolds K, Vogel J, O'Connor J: Soldier performance and mood states following a strenuous road march. Milit Med 1991; 156: 197-200.
4. Rice VJ, Sharp MA, Tharion WJ, Williamson TL: The effects of gender, team size, and a shoulder harness on a stretcher-carry task and post-carry performance: Part I. A simulated carry from a remote site. Ind Ergon 1996; 18: 27-40.
5. Tharion WJ, Rice V, Sharp MA, Marlowe BE: The effects of litter carrying on rifle shooting. Milit Med 1993; 158: 566-70.
6. Tharion WJ, Hoyt RW, Marlowe BE, Cymerman A: Effects of high altitude and exercise on marksmanship. Aviat Space Environ Med 1992; 63: 114-7.
7. Hoffman MD, Gilson PM, Westenburg TM, Spencer WA: Biathlon shooting performance after exercise of different intensities. Int J Sports Med 1992; 13: 270-3.
8. Klein RD, Maxey JL: Analysis of the Threat Oriented Marksmanship Training Capabilities of the Infantry Reported Target System (IRETS). Technical report 1267. Fort Benning, GA, U.S. Army Research Institute for the Behavioral and Social Sciences, 1980.
9. M16A1 and M16A2 Rifle Marksmanship. Army Field Manual (FM) 23-9. Washington, DC, Headquarters, Department of the Army, 1989.
10. Schendel JD, Heller FH, Finley DL, Hawley IK: Use of weaponeer marksmanship trainer in predicting M16A1 rifle qualification performance. Hum Factors 1985; 27: 313-25.
11. Krueger GP: Sustained Military Performance in Continuous Operations: Combat Fatigue, Rest and Sleep Needs. USAARL report 91-19. Ft. Rucker, AL, U.S. Army Aeromedical Research Laboratory, 1990.
12. Harman E, Frykman P, Pandorf C, Tharion W, Mello R, Obusek J, et al: Physiological, Biomechanical, and Maximal Performance Comparisons of Female Soldiers Carrying Loads Using Prototype U.S. Marine Corps Modular Lightweight Load-Carrying Equipment (MOLLE) with Interceptor Body Armor and U.S. Army All-Purpose Lightweight Individual Carrying Equipment (ALICE) with PASGT Body Armor. Technical report T99-9. Natick, MA, U.S. Army Research Institute of Environmental Medicine, 1999.
13. Johnson RF, McMenemy DJ: Target detection, rifle marksmanship, and mood during three hours of simulated sentry duty. Proc Hum Factors Soc 1989; 33: 1414-8.
14. Johnson RF: Rifle Firing Simulation: Effects of MOPP, Heat, and Medications on Marksmanship, pp 530-5. San Antonio, TX, Proceedings of the 33rd Annual Conference of the Military Testing Association, 1991.
15. Johnson RF, McMenemy DJ, Dauphinee DT: Rifle marksmanship with three types of combat clothing. Proc Hum Factors Soc 1990; 34: 1529-32.
16. Johnson RF, Merullo DJ: Effects of Caffeine and Gender on Vigilance and Marksmanship, pp 1217-21. Santa Monica, CA, Proceedings of the Human Factors and Ergonomics Society 40th Annual Meeting, 1996.
17. Ito MA, Johnson RF, Merullo DJ, Mello RP: Rifle Shooting Accuracy during Recovery from Fatiguing Exercise, pp 350-355. Arlington, VA, Proceedings of the 22nd Annual Army Science Conference, 2000.
18. Kobrick JL, Johnson RF, McMenemy DJ: Nerve Agent Antidotes and Heat Exposure: Summary of Effects on Task Performance of Soldiers Wearing BDU and MOPP-IV Clothing Systems. Technical report 1-89. Natick, MA, U.S. Army Research Institute of Environmental Medicine, 1988.
19. Brown S, Day S: Indirect evidence of human skeletal muscle damage and collagen breakdown after eccentric muscle actions. J Sports Sci 1999; 17: 397-402.
20. Cote MG, White DA, Mello RP, Sharp DA, Patton JF: Development and assessment of an online aerobic measurement system. Technical report TR1/79. Natick, MA, U.S. Army Research Institute of Environmental Medicine, 1978.
21. Sawka MN, Foley ME, Pimental NA, Toner MM, Pandolf KB: Determination of maximal aerobic power during upper-body exercise. J Appl Physiol 1983; 54: 113-7.
22. Knapik JJ, Ang P, Meiselman H, et al: Soldier performance and strenuous road marching: influence of load mass and load distribution. Milit Med 1997; 162: 62-7.
23. Tharion WJ, Montain SJ, O'Brien C, Shippee RL, Hoban JL: Effects of military exercise tasks and a carbohydrate-electrolyte drink on rifle shooting performance in two shooting positions. Ind Ergon 1997; 19: 331-9.
24. Heimer S, Medev V, Spirelja A: Influence of postural stability on sport shooting performance. Kineziologija 1985; 17: 119-22.
25. Hoffman MD, Street GM: Characterization of the heart rate response during biathlon. Int J Sports Med 1992; 13: 390-4.